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Determination of exposure to environmental tobacco smoke in restaurant and tavern workers in one US city

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Approximately 173 subjects employed as waiters, waitresses, or bartenders in the Knoxville, TN, Standard Metropolitan Statistical Area collected a sample of air from their breathing zone while at their workplace for one shift. In addition, area samples were placed near the work spaces of many of the subjects. Collected samples were analyzed for respirable suspended particulate matter (RSPM), ultraviolet-absorbing and fluorescing particulate matter, solanesol, 3-ethenyl pyridine (3-EP), and nicotine. Saliva samples were collected from the subjects prior to and within 24 h following their work shift, to confirm their non-smoking status. The range of concentrations of environmental tobacco smoke (ETS) constituents encountered was considerable, e.g., for nicotine, from undetectable to more than 100 $\mu g/m^3$. However, the highest RSP levels observed were considerably lower than OSHA workplace standards. Distributions of ETS concentrations suggest that there are two "ETS exposure" types of bartenders: those that work in single room bars and those that work in larger, multi-room restaurant/bars. Personal exposure to ETS of the former group was ca. 10× greater than those of the latter group, who were exposed to ETS levels more comparable to those encountered by wait staff. Exposure (concentration×duration) differences between wait staff and workers in other types of unrestricted smoking environments reported in other studies suggest that exposures in the restaurant environment may be more difficult to assess than originally considered. Salivary cotinine levels indicated that for those subjects living in *smoking* homes, ETS exposures outside the workplace are at least as important as those in the workplace. *Journal of Exposure Analysis and Environmental Epidemiology* (2000) 10, 36 – 49.

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Introduction

Occupational exposure to environmental tobacco smoke (ETS) has been a subject of considerable interest and regulatory consideration. In 1994, the Occupational Safety and Health Administration (OSHA) proposed severe restrictions on smoking in workplaces (U.S. Department of Labor, 1994). By 1995, 71% of workplaces, as determined by the International Facility Management Association, had reported some form of smoking restriction, as reported by the Congressional Research Service (Redhead and Rowberg, 1995). This is in contrast to 1991, when only 42% of workplaces reported restrictions. Because of the changing nature of smoking in the workplaces, many investigators and public health agencies consider restaurant wait staff and bartenders to be two of the more highly exposed occupational categories. In some cases, states or smaller communities have passed no-smoking ordinances for restaurants or taverns (Glantz and Smith, 1994, 1997; Centers for Disease Control and Prevention, 1995). Several studies have been conducted to determine ETS levels in restaurants or bars (Thompson et al., 1989; Oldaker et al., 1990; Brunnemann et al., 1992; Collett et al., 1992; Turner et al., 1992; Lambert et al., 1993). However, these studies have been limited to either short-duration area measurements or personal monitoring measurements on surrogate "customers." Siegel has reviewed several of these published studies, and concluded that restaurant workers and bartenders receive exposures (concentration×duration) to ETS which are a factor of 1.5 and 4.4, respectively, greater than those received by someone living with a smoker.

Because it captures human activity patterns, personal exposure determination is believed to be a more accurate method than area monitoring for judging the time-averaged concentration to which a worker is exposed. Despite this perception, there have been few reports in the scientific

1. Abbreviations: 3-EP, 3-ethenyl pyridine; EPA, Environmental Protection Agency; ETS, environmental tobacco smoke; FPM, fluorescing particulate matter; HPLC, high-performance liquid chromatography; l/min, liter per minute; $\mu g/m^3$, microgram per cubic meter; μm, micrometer; ORNL, Oak Ridge National Laboratory; OSHA, Occupational Safety and Health Administration; RSP, respirable suspended particulate matter; SMSA, standard metropolitan statistical area; Sol-PM, solanesol-related particulate matter; TSP, total suspended particulates; TWA, time-weighted average; UVPM, ultraviolet-light-absorbing particulate matter.

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literature directed at the determination of personal exposure to ETS for waiters, waitresses, and/or bartenders. In part, this may be due to the fact that it is difficult to get subjects to wear sampling systems when interacting with the public to such a high degree. In a study of personal exposure to ETS conducted by the authors (Jenkins et al., 1996), 14 subjects (of 1564) reported themselves as being in the job class of Waiters/Waitresses/Bartenders (no distinction was made), working in facilities where smoking was permitted, and had a salivary cotinine level which confirmed their non-smoking status. Median 8-h time-weighted average (TWA) levels of 3-ethenyl pyridine (3-EP), nicotine, fluorescing particulate matter (FPM), and ETS particles as determined from solanesol (Sol-PM) were 1.12 $\mu g/m^3$, 3.83 $\mu g/m^3$, 14.6 $\mu g/m^3$, and 5.03 $\mu g/m^3$, respectively. Because of the small sample size, it is difficult to assess conclusively from this data set the personal exposures to ETS for this job classification. The limited number of subjects may have been attributed to the fact that logistical constraints of that study required subjects to work a 35+-h work week on a regular (8 a.m.–5 p.m.) shift. Many workers in this job class simply do not work during those hours.

There have been few direct comparisons of area sampling vs. personal exposure monitoring for ETS constituents. Two studies (Crouse and Oldaker, 1990; Jenkins et al., 1991) focusing on short-duration measurements provided conflicting results. Crouse et al. reported that area samples of ETS nicotine collected with a small, briefcase sampler yielded somewhat higher levels than personal exposure measurements. In the study reported by Jenkins et al. (1991), no difference was found between short-duration area and personal exposure measurements in smoking environments. In a study using ca. 8-h TWA levels reported by Sterling et al. (1996), median personal exposure levels of ETS constituents for 25 subjects in two facilities were not statistically different from those of several area measurements made in the same facility.

The purpose of the study reported here is to provide for an initial determination of the personal exposure to ETS constituents for this occupational class. In addition, placing area samplers in many of the facilities in which the subjects worked during their work periods provided the opportunity to assess the efficacy of using area measurements as a surrogate of personal exposure for this group of workers.

Methods

Study Design

The goal of the study was to recruit a minimum of 80 subjects in each of two occupational categories: waiters/waitresses and bartenders. Subjects were informed that they would be participating in an indoor air quality study, but not that the primary target of the study was ETS constituents. Each subject was to wear a personal air sampling pump for a minimum of 4 h during his/her work shift, with the understanding that some subjects would actually work longer than 4 h. Where possible, area samplers were placed in or near the work areas of the subjects during the period in which personal sampling was being conducted. Although all subjects were recruited on the basis of non-smoking status, salivary cotinine level was used to assess actual smoking status. Because of the anticipated difficulty of recruiting a sufficient number of subjects for the study, no attempt was made to recruit a subject population in such a way as to be demographically representative of the non-smoking members of the classes of occupations on a national, regional, or local basis.

Four institutions were involved in the study: Oak Ridge National Laboratory (ORNL) — staff were responsible for overall study design and implementation, field operations, air sample analysis, and data analysis and reporting; Labstat (Kitchener, Ontario) — responsible for salivary cotinine analysis; Amick Research (Knoxville, TN) — responsible for questionnaire development and organization, subject recruiting, and data coding, as well as assistance with field operations; The Tombras Group (Knoxville, TN) — provided assistance with recruiting and administrative support to Amick Research.

Subject-Recruiting and Resulting Demographics

Field operations were conducted from November 1996 through January 1997. Subjects, (waiters, waitresses, and bartenders) were recruited from the Knoxville, TN, Standard Metropolitan Statistical Area (SMSA) (Knox, Anderson, and Blount counties). Establishments were considered eligible for participation if the seating capacity was greater than 25, and if smoking was permitted in the establishment. Segregation of the establishment into smoking and non-smoking areas was acceptable. Fastfood restaurants were excluded. In terms of the establishments selected, roughly 25% of the total eligible establishments was represented (see below). Virtually every establishment in the phone book was initially contacted. The primary reason for non-participation in the study was failure to reach agreement with the manager. This was particularly true in "chain" establishments. Additionally, in some cases, no employees were non-smokers, which precluded the establishment from participating. However, the establishments included represented the entire range of style, cuisine, and cost in this area.

No more than eight participants were recruited from any one establishment — no more than four bartenders and four servers. Subjects were recruited through direct contact with the manager of the establishment, who was also asked to provide information relative to the smoking habits of the employees. The manager was paid a gratuity, and was also

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allowed to become a subject if the eligibility criteria were met. This step was considered necessary in order to ensure the cooperation of the manager with the study, given the customer-intensive nature of the business. Individual subjects had to report a non-smoking status for 6 months prior to the sampling period, be non-users of nicotine-containing smoking-cessation aids, and be at least 18 years of age. Subjects were screened as to selected occupations of household members or activist affiliations of their own or household members which might bias their participation. Excluded from the study were subjects who lived with journalists and members of the media, the legal, advertising, marketing research, public relations, tobacco manufacturing and distribution professions, and members of anti-smoking groups and selected health groups. Subjects were also excluded if members of their household worked for a branch of the state or Federal government which might have an interest in the outcome of the study.

The subjects were asked to report to a central site for instruction on pump usage and recordkeeping (workplace diaries), and collection of saliva samples. Instruction consisted of a videotape presentation, augmented by an instructor, to ensure that each subject received comparable instruction. Demographic and lifestyle information was collected from the subjects using questionnaires administered during their first and last visits to the test coordination site. (Questionnaire material was similar to that used in a previous study (Jenkins et al., 1996), but reorganized to reflect changes in experimental design.) Saliva samples were collected during the first and last visits. Subjects also received a gratuity for their participation.

In all, 173 subjects participated in the study, of whom eight were excluded from the data compilations reported here because of salivary cotinine levels believed to be indicative of at least occasional active smoking. A discrimination level of 30 ng/ml (Etzel, 1990) was chosen in order to exclude those subjects who may have smoked while wearing the sampling pumps. This level, established prior to the initiation of the study, was twice as high as used in the authors' previous study (Jenkins et al., 1996), because there was greater concern about incorrectly excluding subjects from these occupational categories with perceived higher ETS exposures. Only six subjects had average salivary cotinine levels that fell between 15 and 30 ng/ml.

In general, the demographics of the study population (see Table 1) showed them to be more educated, younger, and have lower household incomes than the US population as a whole. Few non-Caucasians participated in the study. These subject demographics are most likely a reflection of the study being conducted in a town with a large state-supported university and a job which is frequently held by college students. However, no claim as to representativeness relative to other geographic locations is made.

Table 1. Demographic characteristics of restaurant/tavern servers study population (165 subjects) comparison with US population and/or appropriate segments of US population.

	Study population, %	US population, %
Race		*Entire US population*
White[a]	94.9	75.8
Black[a]	2.6	11.8
Hispanic	0	8.8
Other[a]	2.6	3.6
Annual household income		*Entire US population*
<$10 K	9.6	11.8
$10 K–$20 K	34.6	16.4
$20 K–$30 K	20.5	14.7
$30 K–$40 K	14.7	12.3
$40 K–$50 K	9.6	10.4
$50 K–$75 K	9.6	18
$75 K–$100 K	0	8.2
>$100 K	1.3	8.2
Age		*US population ≥18*
18–24	35.5	14.2
25–44	58.1	43.8
45–64	5.8	25.2
65 and +	0.6	16.8
Educational status		*US population ≥18*
Not high school graduate	1.3	24.6
High school graduate	6.4	30.1
Some college	57.7	26.7
College graduate	34.6	18.5
Gender		*US population ≥18*
Male	50	47
Female	50	53

[a]Non-Hispanic.

Sampling Equipment

The sampling equipment was essentially identical to that described by Ogden et al. (1996a) and used previously by the authors (Jenkins et al., 1996). A single, sound-insulated constant-flow pump was used to collect both the vapor phase and particulate phase samples. Vapor phase samples were collected using XAD-4 cartridges (SKC, Eighty-Four, PA) at a rate of approximately 0.7 l/min. Vapor phase samples were analyzed for nicotine and 3-ethenyl pyridine. Particulate phase samples were collected using 37 mm Fluoropore™ filters at a flow rate of 1.7 l/min. Particle phase markers determined as part of this study were: respirable suspended particulate matter (RSP, 4.0 μm or smaller), ultraviolet-absorbing particulate matter (UVPM), fluorescing particulate matter (FPM), and solanesol. A cyclone vortex assembly (Sensidyne, Clear-

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water FL) preceded the filter cassette, such that the material on the filter was all of respirable (<4 μm mass median aerodynamic diameter) size. The sampling systems were assembled at the test coordination site, using the following procedure. Pre-weighed (see *Methods* section) filters identified by bar-code labels were placed in the sampling head. XAD-4 cartridges were labeled, the glass tips broken off, and installed in the sampling head. Using two mass flow meters, the particulate phase flow was adjusted to 1.7 l/min. The resulting vapor phase flow was measured (usually around 0.7 l/min) and recorded. When the sampling systems were returned to the test site by the subjects following sampling, sample durations and flow rates were recorded again. Average flow rates (mean of start and ending) were used to calculate ETS marker concentrations.

Two saliva samples, designated Start and End, were collected with Salivettes (Sarstedt, Newton, NC), which were comprised of a sterile cotton cylindrical swab contained inside a clear plastic centrifuge tube. The Start sample was collected during the first visit of the subject to the test coordination facility, and the End sample was collected approximately 24 h (but sometimes 48 h) later at the same location, when the subjects returned their air sampling systems. Samples were collected by having the subjects open the tube and drop the swabs into their mouths without touching the swab. The swab was chewed vigorously for 60 s, and expelled back into the tube without hand contact. Samples (saliva and breathing zone ETS) were stored in a cooler containing dry ice prior to transport to the laboratory. There, they were stored in freezers at −20°C until analyzed. The saliva samples were shipped on dry ice to the analytical laboratory.

In contrast to work previously reported by the authors, the sampling pump/power pack unit was placed in a lumbar support fanny pack (SunDog, Seattle, WA). The fanny pack acted to minimize movement of the sampling pump, which was considered critical for occupations in which there may be a lot of physical movement of the subject. In addition, it was less conspicuous than the system previously used (Jenkins et al., 1996), which was supported by a shoulder strap. The sampling head was attached to a small lanyard around the neck of the subject, such that the head could be kept in the breathing zone at all times. The sampling pump and sampling head were stored in the fanny pack until use by the subject.

Systems used for area samples were assembled in an identical manner. The same sampling equipment was used, although the use of the fanny pack was not usually required. After identification of the individuals for whom area samples were to be taken as well, the area sampler was delivered and installed at the establishment by ORNL staff. Every attempt was made to match the area sampler with the working area and work shift of the individual, or with that of multiple subjects in the same facility. In many cases, the subjects themselves were instructed to turn off the area sampler when their work shift ended. Digital photographs were taken in order to document the position of the area samplers, and incorporated into the resulting database for this study.

Analytical Methods

Analytical chemical procedures have been described in detail elsewhere (Conner et al., 1990; Ogden, 1991; Ogden and Maiolo, 1992; Ogden et al., 1990). Briefly, gas phase samples were extracted using 1.5 ml ethyl acetate containing 0.5% triethylamine and 8.2 μg/ml quinoline (internal standard). The analysis was performed using a Hewlett-Packard Model 5890A gas chromatograph equipped with a Model 7673 autosampler, a 30M DB-5 capillary column (0.32 mm i.d., 1.5 μm film thickness), and a nitrogen/phosphorus detector. RSP was determined by weighing the filters in triplicate on an electrobalance (Cahn) after overnight incubation at 50% humidity. After sampling, the procedure was repeated, and the difference reported as RSP. The remaining particulate phase markers — UVPM, FPM and solanesol — were determined after extraction of the filter with 3.0 ml methanol. UVPM and FPM were determined simultaneously using a Hewlett-Packard Model 1090 HPLC equipped with an autosampler, a short section of 0.2 mm tubing (to replace the column), and sequential diode array and fluorescence detectors. Solanesol was determined using a Hewlett-Packard model 1090 HPLC equipped with an autosampler, a Spherisorb-ODS column (4.6 mm i.d., 25 cm long) and a diode array detector operated at 205 nm. The mobile phase was 100% methanol. All values were measured in microgram per sample, and converted to microgram per cubic meter using the flow duration data. Salivary cotinine was determined using gas chromatography with nitrogen-specific detection (Jacob et al., 1981).

Quality Control

For each day that either area samples or personal samples were sent out, a field blank was taken. To generate the field blank, the sampling unit was completely assembled, subjected to an initial flow check, and stored at the staging area until the sampling systems with which the field blank was associated were returned. Finally, the unit was subjected to a final flow determination, identically to a completed sample. These field blank samples were analyzed blind with the actual subject and area samples for all of the analytes. For RSP measurements, each filter was incubated in a controlled humidity chamber (50% relative humidity) for 24 h prior to weighing. The filters were then placed under an ionizing unit (Staticmaster, NRD, Grand Island, NY) for 5–10 min to eliminate static electricity effects. The filters were then weighed. This process was repeated in triplicate for all of the filters, and

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Table 2. Analytical LOD and fraction of samples at or below those limits.

	LOD, μg/sample					
	RSP	UVPM	FPM	Sol-PM	3-EP	Nicotine
	25	6.8	1.9	4.95	0.0375	0.030
	Percent of samples at or below effective concentration LOD[a]					
Area samples	28.2	34.1	2.4	32.9	9.4	10.6
Personal exposure samples	29.8	46.0	6.2	37.9	11.8	14.3

[a]Computed on the basis of individual sampling durations and mean flow rates, relative to the LOD in terms of mass per sample. See text for more detail.

the result was reported as the average of the three weighings. For the remaining chromatographic analyses, calibration curves contained a minimum of seven levels, method blanks were run at a minimum of one for every 10 samples, and calibration checks were made at a similar frequency for the entire calibration range. Because of the consumptive nature of the extractions, it was not possible to obtain true duplicate analysis. For the saliva samples, field blanks were chewed by members of the operations team whose exposure to ETS was deemed to be very low, and analyzed blind by Labstat.

Limits of Detection

Limits of detection (LOD), in terms of microgram per sample, are reported for the air markers in Table 2. (The limit of quantification for the salivary cotinine was 1.0 ng/ml.) In general, a value of 3× the standard deviation of repeated analyses of the method blanks was used as the criterion for the LOD. RSP had the highest LOD, 25 μg/sample, while nicotine had the lowest LOD, at 30 ng/sample. In terms of air marker concentrations, the LOD for an individual sample depends on the sample volume, which in turn is dependent on the sampling flow rate and duration. Also reported in Table 2 is the fraction of samples which were at or below the LOD for each of the air constituents. In general, a slightly smaller fraction of the area samples was at or below the LOD, compared with the personal exposure samples. This may be due to somewhat longer sampling durations for the area samples. There was considerable variation in the reported fractions, from 2.4% for FPM in the area samples, to 46% for UVPM in the personal exposure samples. In no case did the fraction exceed 50%.

Results and discussion

Study Sample Composition

The final subject base included 85 restaurant wait staff and 80 bartenders. The total number of establishments in which the subjects worked was 49. Area samplers were placed in 85 separate locations within these facilities. While we believe that the methods used in recruiting did not bias the composition of the subject base, it is interesting to compare the demographic information with what would normally be expected from the U.S. population in general. In this study (Table 1), the subject population tended to be young, well-educated, and of low income. Those participants in the higher age brackets tended to be either owners of the establishment or to be employees at more upscale establishments. This suggests that for these subjects as an occupational group, these jobs are temporary, either until finishing college or acquiring a permanent job.

Two general challenges were encountered during the recruiting process. First, recruiting an adequate number of bartenders who fit the study design was difficult. Based on manager survey responses, we found that the fraction of bartenders who were current non-smokers was only about 50%. In some establishments, the fraction was less than 20%. Secondly, there was some difficulty in obtaining agreement from managers to allow participation of employees in the study. This was particularly true of chain restaurants, where the restaurant manager needed to get approval from a regional manager. There was a perception among the managers that the dining/entertainment experience of customers who observed wait staff or bartenders wearing the pumps would be diminished.

In the Knoxville SMSA, there are approximately 350 establishments listed in the Yellow Pages as either restaurants or taverns (not including the fastfood group). Of these, about 30% are regional/national chains, with the remaining 70% being locally owned and operated. As mentioned above, difficulty was encountered recruiting subjects who worked in the chain restaurants. Only 10% of the establishments in the study represented regional/national chains, although these establishments accounted for 20% of the area samples and almost 20% of the study participants. Also, according to the Alcoholic Beverages Commission, there are 148 establishments in Knox County which are licensed to sell liquor by the drink. Forty-two of those were participants in this study.

Based on observations made during subject recruiting and placement of area samplers, it became apparent from the wide range of environments that it would be useful to characterize the establishments in terms of the services provided and physical nature of the customer service area. Four classifications were derived: Single-room bar; no

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Table 3. Spearman rank correlation coefficients for personal exposure samples.

	UVPM	FPM	RSP	Sol-PM	Nicotine	3-EP
UVPM	1.000	0.952	0.722	0.850	0.781	0.756
FPM	0.952	1.000	0.753	0.896	0.824	0.785
RSP	0.722	0.753	1.000	0.615	0.647	0.658
Sol-PM	0.850	0.896	0.615	1.000	0.806	0.734
Nicotine	0.781	0.824	0.647	0.806	1.000	0.890
3-EP	0.756	0.785	0.658	0.734	0.890	1.000

partitions, primary service is beverages; Single-room restaurant/bar: no partitions, but serving a full menu of food; Multi/room restaurant/bar: both full bar and full service menu, more than one distinct area; and Restaurant only: no bar.

Of the restaurant/tavern facilities in the Knoxville SMSA, about 15% would be classified as single room bars, with the other three categories each making up about 25–30%. (Note that these fractions do not account for the study requirement that qualifying facilities had to have a minimum of 25 customer seats.) In this study, 30% of the establishments was single room bars, 20% single room bar/restaurant, 10% restaurant only, and 40% multi-room bar/restaurant. Based on manager reports, ca. 28% had seating capacities between 25 and 100, 35% between 101 and 200, 24% between 201 and 300, and 13% greater than 300.

ETS Marker Levels

In Table 3 are summarized the Spearman rank correlation coefficients for the personal exposure samples. All of the

Table 4. Concentrations of ETS constituents in area and personal exposure samples subjects with average salivary cotinine >30 ng/ml and/or sampling time <3.0 h excluded.

		ETS component concentrations, g/m^3						
		RSP	UVPM	FPM	Solanesol	Sol-PM	3-EP	Nicotine
Area samples								
Non-bar areas, $N=32$	Median	66	10.2	16.8	0.327	10.8	0.580	0.818
	Mean	73	29.4	29.3	0.619	20.4	1.44	6.01
	Standard deviation	67	44.2	32.5	0.840	27.7	2.13	11.9
	Minimum	0	0.0	2.1	0.000	0.0	0	0
	Maximum	233	174	151	3.72	123	8.83	49.3
	80th percentile	117	47.4	40.6	1.10	36.3	1.92	6.96
	95th percentile	200	125	86.5	1.98	65.4	5.37	34.2
Bar areas, $N=53$	Median	82	48.5	35.4	0.827	27.3	1.16	5.80
	Mean	135	95.0	90.6	2.24	74.0	3.48	14.4
	Standard deviation	146	115	107	3.08	102	3.85	16.9
	Minimum	0	0.0	1.9	0.000	0.0	0.00	0.00
	Maximum	768	449	436	11.9	393	16.1	61.3
	80th percentile	228	171	154	4.70	155	7.23	29.4
	95th percentile	369	331	326	9.13	301	10.2	45.0
Personal exposure samples								
Bartender, $N=80$	Median	112	43.3	40.6	0.826	27.3	1.17	4.45
	Mean	151	100	98.4	2.33	77.0	3.31	14.1
	Standard deviation	130	127	118	3.20	106	4.12	20.9
	Minimum	0	0.0	2.2	0.00	0.0	0	0.000
	Maximum	511	487	453	14.3	473	23.6	116
	80th percentile	239	168	158	4.27	141	5.96	27.1
	95th percentile	428	377	370	10.6	350	10.3	43.5
Wait staff, $N=83$	Median	82	6.2	20.0	0.226	7.5	0.59	1.16
	Mean	110	36.9	37.2	0.768	25.3	1.73	5.83
	Standard deviation	111	58.7	45.2	1.19	39.3	2.84	11.9
	Minimum	0	0.0	0.5	0.00	0.0	0.00	0.00
	Maximum	474	288	243	4.98	164	14.9	67.9
	80th percentile	182	73.9	56.3	1.12	37.0	2.62	6.12
	95th percentile	386	160	127	3.75	124	6.68	28.9

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values are considered to be highly significant ($p<0.01$). The lowest correlations were found between RSP and the tobacco-specific markers, Sol-PM, 3-EP, and nicotine. There are multiple sources of RSP, in addition to ETS, likely to be present in these environments, so correlations would be expected to be lower.

In Table 4 are summarized the ETS constituent concentrations for both the personal exposure and area monitoring samples. The range of concentrations in the personal exposure samples is considerable. For example, nicotine levels encountered by bartenders ranged from undetectable to more than 100 $\mu g/m^3$, while RSP levels ranged from undetectable up to 511 $\mu g/m^3$. Comparing the bartenders to the wait staff, median concentrations for bartenders were generally two- to four-fold greater for ETS constituents other than RSP — a non-tobacco-specific marker. (Note that the median UVPM levels for the wait staff were abnormally low, due to higher-than-expected detection limits for this class of samples. Concentrations below the detection limits were taken as 0 for this compilation.)

When analyzing the data in terms of the type of establishment, it became apparent that there are large differences in levels of ETS constituents encountered within the bartender occupational category related to the type of work environment. Comparing the cumulative distributions for nicotine between bartenders in single room bars and bartenders in multi-room restaurant/bars, Figure 1 indicates a concentration difference of an order of magnitude. The distribution of the nicotine levels for the bartenders in the multi-room bar/restaurants is comparable to that of the wait staff in all facilities. Similar differences in levels were noted for the other tobacco-specific markers.

Concentrations determined from the area sampling exhibited a similar wide range. For example, nicotine levels ranged from undetectable to 61 $\mu g/m^3$ in bar areas. FPM levels ranged from 2 to 436 $\mu g/m^3$. The maximum RSP level measured in all the areas was 768 $\mu g/m^3$, approximately a factor of 6.5 less that the OSHA-mandated 8-h TWA level of 5000 $\mu g/m^3$ for respirable particulates. In general, taken as a group, the area concentration measurements were not dissimilar from the personal exposure levels. This is discussed in greater detail below. Siegel (1993) has reviewed earlier studies in restaurants and bars, and reported weighted means. Nicotine concentrations in our study (means: 14.4 $\mu g/m^3$ for bar areas and bars, and 6.01 $\mu g/m^3$ for restaurants) were similar to those reported by Siegel (19.7 and 6.5 $\mu g/m^3$, respectively). However, the RSP levels in this study (67 $\mu g/m^3$ and 135 $\mu g/m^3$ for restaurants and bar areas) were considerably lower than those summarized by Siegel (117 $\mu g/m^3$ and 348 $\mu g/m^3$, respectively). However, Siegel did not specify whether "particulates" were respirable only (RSP) or total suspended particulate matter (TSP). Lambert et al. (1993) reported comparisons of area samples in smoking and non-smoking sections of a small number restaurants in one US

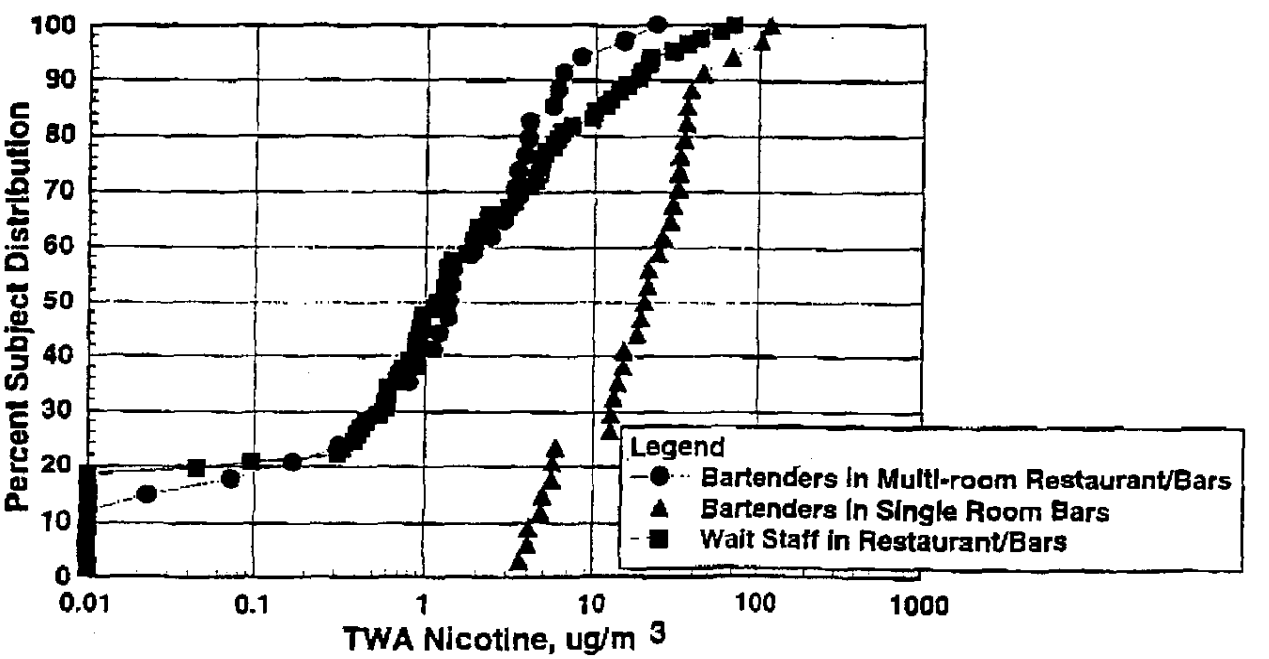

Figure 1. Cumulative distributions of study subjects segregated by job classification and work venue, as a function of shift length nicotine concentration.

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Table 5. Median ETS component concentrations wait staff and bartenders in this study vs. waiters/waitresses/bartenders in 16 cities study[a].

Subject group	Median ETS component concentrations, $\mu g/m^3$				
	RSP	FPM	Sol-PM	3-EP	Nicotine
Bartenders, $N=80$	112	40.6	27.3	1.17	4.45
Wait staff, $N=83$	82	20.0	7.5	0.59	1.16
Waiters/waitresses/ bartenders in 16 cities study, $N=14$	43	14.6	5.0	1.12	3.83

[a]Jenkins et al. (1996).

city. When the results of our area sampling are segregated by smoking and non-smoking areas, the results are fairly comparable to or somewhat higher than those reported by Lambert. For example, for samples collected in this study in smoking areas, median RSP and nicotine levels were 66 $\mu g/m^3$ and 7.7 $\mu g/m^3$, respectively, compared with 53.2 $\mu g/m^3$ and 3.2 $\mu g/m^3$ reported by Lambert. For area samples collected in non-smoking areas in this study, median RSP and nicotine levels were 48 $\mu g/m^3$ and 0.8 $\mu g/m^3$, respectively, compared to those reported by Lambert of 42 $\mu g/m^3$ and 1.0 $\mu g/m^3$. Thus, results of this study confirm that exposure to ETS is reduced for non-smoking customers by establishing separate areas in facilities, and that the exposure to nicotine is reduced to a greater degree than is exposure to particulate matter.

It is difficult to draw direct comparisons between personal exposure concentration results from this study with those of a similar occupational class in the previous 16 cities study (Jenkins et al., 1996), because in the latter, no distinction was made between wait staff and bartenders. However, because of the work shift requirement, it is likely that there were few bartenders in the 16 cities study. Interestingly, work shift average levels for the earlier study for the measured vapor phase ETS constituents fall between those of the wait staff and bartenders in this study (see Table 5). However, the particle phase constituent levels measured in the previous study tend to be lower than those of the wait staff (the group from this study exposed to smaller concentrations of ETS). Differences may be due to the time of day in which samples were collected (mostly evening for this study, vs. daytime for the 16 cities subjects).

When the ETS constituent levels are sorted by gender and occupational class for this study, one interesting finding emerges. For bartenders, there appear to important gender-related trends (see Table 6). For example, median levels of ETS vapor phase constituents to which male bartenders were exposed were greater than those to which female bartenders were exposed. Median levels of Sol-PM and FPM were also higher, but those of RSP and UVPM were slightly lower. However, for wait staff, females encountered higher ETS constituent levels across the distributions (median, mean, 80th percentile, etc.) for virtually all ETS constituents, with the exception of RSP. (Note that the difference between median Sol-PM levels for male and female wait staff was not significant at the $p=0.05$ level.) This suggests that waitresses may be exposed to higher levels of ETS components than waiters. Sampling across a broader variety of geographic locations would need to be performed to confirm this preliminary finding.

Table 6. Summary of levels of ETS components to which subjects were exposed segregation by occupational category and gender.

Subject occupational category	Gender		Total smoking products observed	Sample duration, h	ETS component concentrations, $\mu g/m^3$					
					RSP	UVPM	FPM	Sol-PM	3-EP	Nicotine
Wait staff	Female, $N=45$	Median	12	4.7	107	12.3	24.3	12.8	0.70	1.27
		Mean	26	4.9	110	48.3	45.9	32.4	2.33	8.18
		80th percentile	49	5.5	159	85.2	71.6	62.7	4.11	14.16
		95th percentile	89	6.7	350	171	156	135	6.69	34.06
	Male, $N=36$	Median	8	4.5	73	4.2	16.4	4.4	0.53	1.20
		Mean	14	4.8	110	24.7	27.8	17.9	1.06	3.17
		80th percentile	22	5.3	201	30.0	34.6	28.7	1.41	3.98
		95th percentile	45	6.3	333	141	105	63.4	2.93	10.13
Bartenders	Female, $N=35$	Median	24	5.3	118	52.5	36.7	23.6	0.89	3.41
		Mean	110	5.4	162	108	99.1	81.5	3.41	14.46
		80th percentile	73	6.3	287	186	169	148	6.76	21.76
		95th percentile	373	7.8	421	386	352	292	11.95	61.60
	Male, $N=44$	Median	43	5.18	112	43.3	43.4	30.9	2.51	5.85
		Mean	72	5.52	145	96.6	99.9	74.8	3.30	14.16
		80th percentile	108	6.69	222	159	147	127	5.41	28.12
		95th percentile	264	8.21	409	368	361	330	9.79	39.57

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Cotinine Results

Of the 173 subjects whose sampling pumps worked long enough to obtain meaningful data, eight were excluded because they were deemed to have mis-reported their current smoking status. The criterion for exclusion was an average (of start and finish) salivary cotinine level of >30 ng/ml. This level is considered to be the highest concentration which could reasonably expected to be encountered in individuals who are true non-smokers (Etzel, 1990), receiving nicotine exposure only from secondary sources (i.e., ETS). In its risk assessment of ETS exposure and lung cancer, the US Environmental Protection Agency effectively defined the level of salivary cotinine at which non-smokers can be discriminated from "occasional" smokers as 10% of the mean salivary cotinine level of all self-reported smokers (U.S. Environmental Protection Agency, 1993). In a nationally representative study of salivary cotinine levels, Ogden et al. (1997) reported the mean level of all smokers to be 350 ng/ml. Thus, 10% of that value is 35 ng/ml, a level with no operational difference from the 30 ng/ml used in this study (i.e., no subjects fell within the range of 30–35 ng/ml). For the subjects which were excluded in our study from further consideration, ETS nicotine levels encountered were not particularly high: median=0.58 $\mu g/m^3$, although the mean level was >10× higher, due to one individual's high level.

For this study, we made no direct comparison between measured nicotine exposure and salivary cotinine. Direct measurement of ETS nicotine exposure was not performed on these subjects for a substantial fraction of their day. Primarily, no personal exposure samples were obtained away-from-work using a second collection system. Secondly, for a large portion of the subjects, it is clear that the entire work shift was not covered by the sampling period, although for most of the subjects, the difference in time was small. Thus, comparison of an integrated measurement such as salivary cotinine with a 4–6-h measurement of nicotine exposure was believed to serve no purpose.

While data from a study previously conducted by the authors (Jenkins and Counts, 1999; Jenkins et al., 1996) have demonstrated little correlation between *individual* salivary cotinine levels and *individual* 24-h nicotine exposures, on a group basis, median or mean levels of salivary cotinine are highly correlated with median/mean ETS nicotine exposures. Judging from the group statistics for salivary cotinine in this study, for wait staff and bartenders who live with smokers, exposure to ETS outside the workplace appears to be at least as important as exposure in the workplace. For example, in Table 7 are reported group statistics for salivary cotinine levels by job category and home smoking status. Median salivary cotinine level for bartenders living in smoking homes was 4.35 ng/ml vs. 2.00 ng/ml for bartenders living in non-smoking homes. (Smoking status of the homes was judged by self-reports of whether regular occupants of the home, other than the subject, smoked at home. The difference in medians is statistically significant at the $p=0.01$ level.) The same trend was observed for the wait staff. Based on the shift average nicotine concentration to which groups were exposed in the

Table 7. Salivary cotinine and shift average nicotine concentrations: impact of job classification and smoking status of home.

Home status	Job classification		Sampling duration, h	Salivary cotinine concentration, ng/ml			Shift average nicotine concentration, $\mu g/m^3$
				Start	End	Average of Start and End	
Smoking	Wait staff, $N=24$	Median	4.73	3.60	3.10	4.08	3.20
		Mean	4.98	4.00	4.05	4.32	12.1
		80th percentile	5.91	6.50	6.05	6.05	17.8
		95% percentile	6.70	9.44	10.8	11.1	54.0
	Bartenders, $N=29$	Median	5.33	3.60	4.35	4.85	12.6
		Mean	5.76	6.46	5.97	6.54	19.2
		80th percentile	6.75	8.56	6.60	8.97	33.2
		95th percentile	8.56	20.6	19.5	20.2	57.9
Non-smoking	Wait staff, $N=58$	Median	4.53	1.20	1.30	1.43	0.93
		Mean	4.79	2.56	2.66	2.61	3.32
		80th percentile	5.31	3.28	3.80	3.62	4.47
		95th percentile	6.21	7.49	7.46	8.24	18.2
	Bartenders, $N=51$	Median	5.06	1.80	2.00	2.00	3.90
		Mean	5.31	3.14	4.24	3.67	11.2
		80th percentile	6.23	4.30	5.50	4.90	20.1
		95th percentile	7.93	12.6	16.2	12.8	34.9

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Table 8. Correlation between ETS constituent concentrations: area monitoring samples vs. personal exposure samples (N=74 pairs).

Constituent	Correlation coefficient, R	Coefficient of determination, R^2
RSP	0.659	0.434
UVPM	0.853	0.727
FPM	0.856	0.732
Solanesol	0.899	0.809
3-EP	0.736	0.541
Nicotine	0.699	0.488

workplace, it may at first appear that on-the-job exposure is the chief contributor to the difference. For example, bartenders living in smoking homes were exposed to higher levels of ETS nicotine on the job than bartenders living in non-smoking homes (median levels 12.6 $\mu g/m^3$ vs. 3.9 $\mu g/m^3$). However, while the median shift average nicotine concentration for bartenders living in non-smoking homes was nearly comparable to that of wait staff living in smoking homes, there was a two-fold difference in the median salivary cotinine levels. Thus, difference in at-work nicotine exposure does not seem to account for differences in cotinine levels. It should be noted that analysis of data from the previous ETS exposure study (Jenkins et al., 1996) has suggested that subjects living with smokers are less averse to ETS exposure in the workplace, and frequently encounter higher ETS levels. Such may account for differences observed in this study.

Comparison of Area Monitoring and Personal Exposure ETS Levels

When considered in a group-wise fashion, the agreement between concentrations found in area samples and those determined by personal monitoring was very good. For example, median levels of UVPM, 3-EP, and nicotine for area samples collected in the bar areas were 48.5 $\mu g/m^3$, 1.16 $\mu g/m^3$, and 5.80 $\mu g/m^3$, respectively. Comparable concentrations for personal exposure samples for the bartenders were 43.3 $\mu g/m^3$, 1.17 $\mu g/m^3$, and 4.45 $\mu g/m^3$, respectively. (See Table 4. Note that not all subjects had an association with an area sample. Thus, N for bartenders+servers is lower than the total number of subjects.) Not only was this the case for median and mean values, but there was significant agreement at the extremes of the distributions. On the surface, this would suggest that at least for these occupational categories in this urban area, area samples provided a good estimation of the average exposure to ETS. If this finding were repeated with national data obtained in a broader study, it might suggest that area sampling would be a cost-effective and simpler alternative to personal monitoring. For example, looking only at the statistical summary data presented in Table 4, one might conclude that it would be sufficient to collect only area samples to estimate individual exposure to ETS components.

This study was designed so that most of the area samples were collected in concert with the shift of individual subject(s), and as such, affords a direct comparison between area and personal breathing zone samples on a

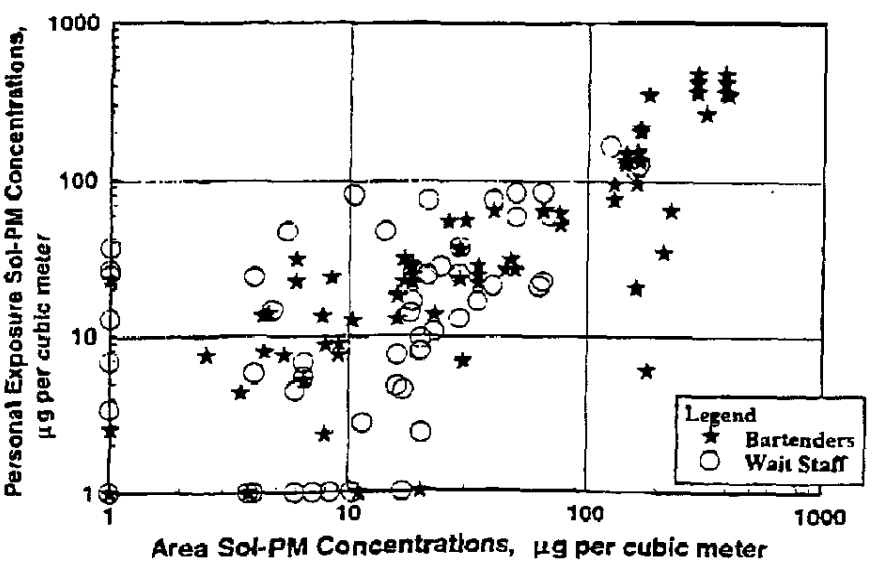

Figure 2. Comparison of Sol-PM concentrations determined by personal exposure measurements vs. by area sampling, segregated by job classification. Only subjects for which both measurements are available are included. Note logarithmic scales.

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subject by subject basis. When this comparison is made, the overall correlations were good. For example, correlation coefficients, R, for solanesol and nicotine were 0.90 and 0.70 (see Table 8). These values are quite similar across the suite of markers. While several of the measurements were non-detects, and set to zero for the purpose of this compilation, the influence of the "zero levels" on the observed correlation is minimal at best. For example, the coefficient of determination, R^2, was determined to be 0.799 for Sol-PM for the bartender area vs. personal comparison. Elimination of all data pairs that contained a zero (total of nine pairs) reduced the R^2 to 0.788. For nicotine and Sol-PM, the biggest reduction of R^2 due to elimination of data pairs containing a zero value was the Sol-PM for the wait staff. Elimination of 33 data pairs reduced the R^2 from 0.635 to 0.580.

However, the data also indicated the area samples were useful for estimating *individual* personal exposures to ETS only to within an order of magnitude, at best. For example, in Figures 2 and 3 are compared the pairs of personal exposure concentration with those of area samples for Sol-PM and nicotine, respectively. At nearly any specific area Sol-PM or nicotine concentration, personal exposure levels varied by one to two orders of magnitude. For example, for area samples with a value of approximately 5 $\mu g/m^3$ personal exposure levels ranged from ca. 0.4 $\mu g/m^3$ to ca. $\mu g/m^3$ for the waiters and waitresses in the study. The extent of variation appears comparable for both wait staff and bartenders. The range of variation of personal exposures is even greater at lower ETS constituent levels (<1.0 $\mu g/m^3$ for nicotine, and <10 $\mu g/m^3$ Sol-PM). Comparisons of other markers showed similar ranges of values. The ranges of personal levels encountered at a given area level are not particularly surprising, given the range of ventilation systems in the facilities in this study, and differences in activity patterns and microenvironments among the subjects. Overall, these data support the hypothesis that individual exposure can be best estimated by personal breathing zone sampling.

Comparisons of Exposures

Because of the higher concentrations of ETS components to which they were exposed, bartenders had two- to four-fold higher exposures than wait staff, despite comparable work shift duration (see Table 9). This is not an unexpected finding. Interestingly, the comparison between exposures of wait staff, and those of the subjects in the 16 cities study (Jenkins et al., 1996) who worked in environments where

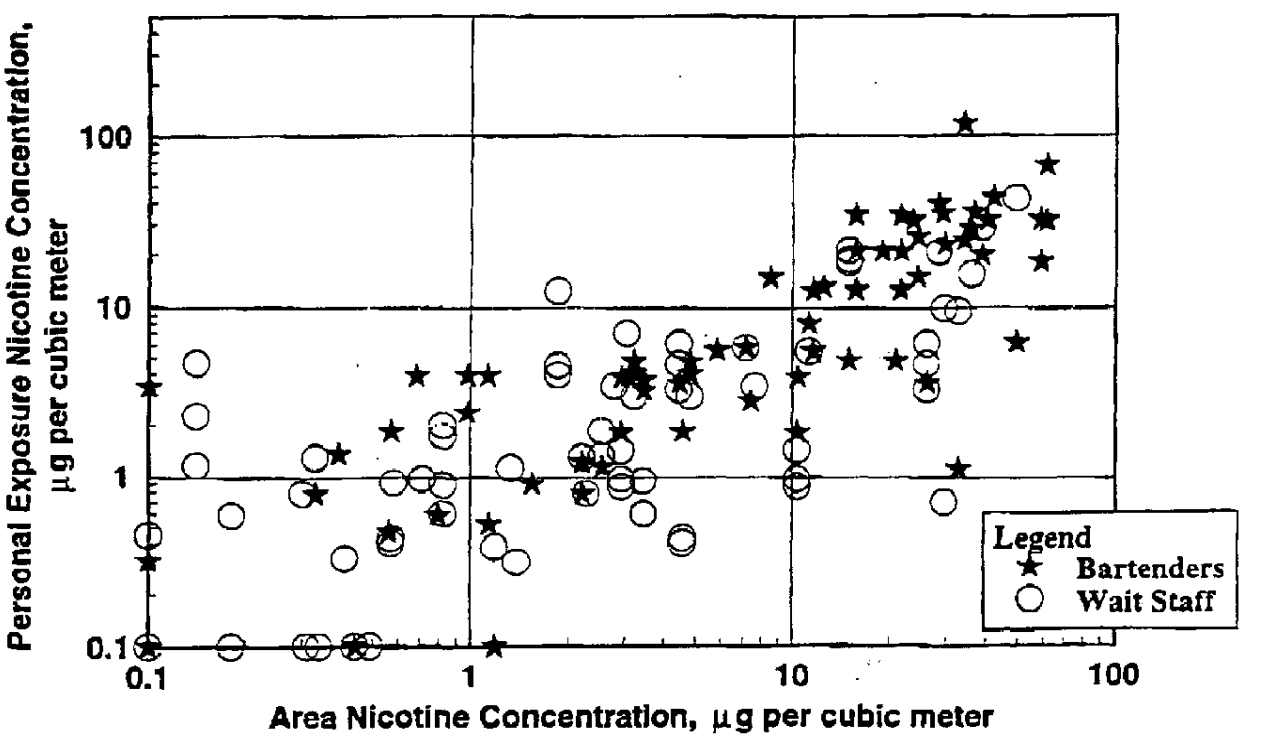

Figure 3. Comparison of nicotine concentrations determined by personal exposure measurements vs. by area sampling, segregated by job classification. Only subjects for which both measurements are available are included. Note logarithmic scales.

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Table 9. Constituent exposures (duration×concentration, in $\mu g\ h/m^3$) for subjects in this study compared with subjects working in environments where smoking was unrestricted, 16 cities study.

		Shift length, h	Constituent exposures, $\mu g\ h/m^3$				
			RSP	FPM	Sol-PM	3-EP	Nicotine
Bartenders, $N=80$	Median	5.2	575	209	129	5.77	22.4
	Mean	5.5	851	576	453	18.91	81.5
	80th percentile	6.7	1462	1005	792	31.5	163
	95th percentile	8.2	2404	2195	1973	60.7	343
Wait staff, $N=82$	Median	4.6	382	91.4	37.8	2.90	5.55
	Mean	4.9	523	189	133	8.87	30.0
	80th percentile	5.5	844	300	164	11.3	34.2
	95th percentile	6.8	1583	777	564	45.5	158.7
16 cities subjects in unrestricted smoking workplaces, $N=134$	Median	8.2	306	59.2	8.92	3.94	8.48
	Mean	8.2	489	186	113	10.9	25.8
	80th percentile	9.0	614	237	110	14.7	36.8
	95th percentile	9.0	1311	764	519	48.7	113

smoking was unrestricted, is more complex. For example, median exposures to combustion-derived particulates (FPM), as well as ETS-specific particulates (Sol-PM), are higher for the wait staff. (Mean levels are closer to comparability.) However, median exposures of the wait staff to ETS-derived vapor phase components, nicotine and 3-EP, are somewhat lower. Note that the differences for the gas phase constituents are approximately proportional to differences in shift length. That the wait staff might be exposed to somewhat higher levels of combustion-derived particulate matter (FPM) is not surprising, given the degree of cooking that occurs in restaurants, compared with other workplaces. Above the 50th percentile, the exposures over 4–5 h work shifts for the wait staff were not dissimilar from those experienced by 16 cities subjects in unrestricted smoking workplaces over 8-h shifts. Exposures of bartenders were clearly higher.

Siegel, in his summary assessment of ETS levels in restaurants and bars, estimated that restaurant workers — presumably waiters and waitresses — receive exposures to ETS that are at least 1.5× greater than those received by non-smokers living in smoking homes. For bartenders, the difference was estimated by Siegel to be 4.4-fold. A comparison of the personal exposure data reported here with that from the authors' previous study (Jenkins et al., 1996) does not support these estimates. For example, the median workplace ETS nicotine exposure for wait staff in this study was ca. 5.6 $\mu g\ h/m^3$, compared with away-from-work exposures of subjects resulting from unrestricted spousal smoking measured in the authors' previous study (Jenkins et al., 1996) of 22.1 $\mu g\ h/m^3$. (Note that some of the subjects worked longer shifts than their pump was actually sampling. For waiters, correcting the ETS exposure upward for the contribution of this longer shift duration would have been small, an increase of ca. 20% or less for most wait staff, and ca. 8% or less for bartenders.) For bartenders in this study, the median work place ETS nicotine exposure was 22.4 $\mu g\ h/m^3$, only very slightly greater than that from spousal smoking determined in the 16 cities study of 22.1 $\mu g\ h/m^3$. For RSP, median exposure for bartenders was 575 $\mu g\ h/m^3$, vs. 523 $\mu g\ h/m^3$ from spousal smoking. At the extremes of the exposure distributions, workplace exposure for these bartenders was substantially greater than that from spousal smoking. For example, at the 95th percentile level (both studies), bartender nicotine exposure was 343 $\mu g\ h/m^3$, compared with 113 $\mu g\ h/m^3$ for away-from-work exposure from spousal smoking. Note however, that the three-fold difference is less than that estimated by Siegel.

The fraction of inhalable particulate matter comprised of ETS-derived particulate matter (Sol-PM) appears to be

Table 10. Sol-PM:RSP ratios for subjects by job classification comparison of results from this study vs. 16 cities study[a].

	This study		16 cities study[a]	
	Wait staff	Bartenders	Waiters/waitresses/bartenders	All subjects working in unrestricted smoking environments
Median	0.085	0.39	0.12	0.031
Mean	0.31	0.46	0.25	0.17
80th percentile	0.42	0.66	0.46	0.29

[a]Jenkins et al. (1996).

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greater for wait staff and bartenders, relative to workers in broader job classifications where smoking is unrestricted. For example, in Table 10 are compared the Sol-PM:RSP ratios for subjects in this study, compared with the waiter/waitress/bartender classification and all workers in unrestricted smoking workplaces from the authors' earlier study (Jenkins et al., 1996). Based on the distributions presented in Table 10, bartenders work in an environment where ETS appears to comprise a larger fraction of the RPM. In general, the distribution of Sol-PM:RSP ratios for wait staff in this study was comparable to that of the waiter/waitress/bartender job class in the 16 cities study, but higher than that of subjects working in unrestricted smoking environments. However, when these data are compared with that in Table 9, which contrasts exposures in these environments, the situation becomes more complex. For example, in Table 9, while the exposure of the wait staff in this study to the vapor phase components of ETS was lower than that of the 16 cities subjects in unrestricted smoking workplaces, the exposure to Sol-PM (and FPM) was higher. This suggests that the relationship between ETS particle and vapor phase constituents may be different for the restaurant/bar environment than for other smoking environments. There are certain features of the restaurant environment which might contribute to this effect. Solanesol and FPM are known to be degraded by light (Ogden and Richardson, 1996). Many of the restaurants in this study were relatively dark, suggesting that the rate of pre-collection degradation of the solanesol may not be the same as that in other working environments where higher intensities of light are present. The extent to which high-temperature cooking of solanaceous vegetables (e.g., tomatoes, green peppers, eggplants) in these environments could contribute to airborne solanesol is unknown, but may further complicate interpretation of the data. To address this issue would require a specifically targeted study. Interestingly, the mean ratio of ETS-derived RSP, taken as Sol-PM, to nicotine for all data pairs (both area and personal) which were non-zero (with three outliers excluded) was 10:2. This is nearly identical to the ratio of 10:1 that many investigators believe exists between ETS-derived RSP and nicotine (Jenkins et al., 1996). However, many investigators have mistakenly concluded that virtually all RSP in areas in which smoking occurs are derived from ETS, which, as the Sol-PM:RSP ratios clearly demonstrate, is not the case.

Conclusions

While the job classification of restaurant wait staff and bartenders may generally be considered to be more highly exposed to ETS, data from this study suggest that the situation is more complex. First, there appears to be at least two classes of bartenders: those that work in single room/area facilities which are predominantly devoted to consumption of alcoholic beverages, and those that work as bartenders in larger facilities, such as a multi-room restaurant/bar which has a greater emphasis on the serving of food. ETS concentration distributions suggest that the former group encounters levels of ETS which are perhaps 10-fold greater than those in the latter group. Distribution functions indicate that the latter group is exposed to ETS components at levels comparable to those encountered by waiters and waitresses.

Exposures (concentration×duration) to ETS of wait staff to ETS vapor phase components ranged from somewhat lower than to that comparable to those of other workers in environments where smoking is unrestricted. This is more a result of short shifts worked by the wait staff, rather than lower or comparable ETS concentrations encountered. However, exposures to ETS-derived particulate matter (Sol-PM) and other combustion-derived particulates is greater for the wait staff (and bartenders). The extent to which differences in ventilation patterns and cooking practices contribute to this phenomenon is unknown. Median workplace ETS exposures of wait staff in this study were much lower than from those away-from-work due to spousal smoking measured in the authors' previous study, and that bartender exposures were only slightly higher. For the most highly exposed bartenders, workplace exposures were a factor of 3 greater than the away-from-work exposure associated with living with a smoking spouse. However, while no direct determination of personal exposure to ETS outside the workplace was performed as a part of this study, salivary cotinine data suggest that for those wait staff and bartenders living in smoking homes, the environment away from work is at least as important a source of exposure to ETS as the workplace.

Comparison of the ETS concentrations from area samples and those from personal exposure monitoring suggests that for at least the environments encountered in this study, with large numbers of samples, it may be possible to estimate overall personal exposure from area samples. However, the results also clearly indicate that on a subject by subject basis, area sampling is limited to predicting individual personal exposures to within a factor of 10.

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